African Invertebrates Vol. 44 (1) Pages 253–264 Pietermaritzburg August, 2003

A soil population of *Lithobius tricuspis* Meinert in a Mediterranean forest (Chilopoda, Lithobiomorpha: Lithobiidae)*

by

Antoni Serra and **Carme Miquel**

(Departament de Biologia Animal, Facultat de Biologia, Universitat de Barcelona.
Avda. Diagonal, 645. E-08028 Barcelona, Spain; aserra@ub.edu)

ABSTRACT

This work was performed in an experimental plot in the Parc Natural de Sant Llorenç de Munt, Barcelona, Spain, in a sclerophilous forest of Mediterranean climate. This forest is made up mainly of *Quercus ilex* and *Pinus halepensis* trees and the most important bush species is *Arbutus unedo*. The litter is of leptomoder type, with an average pH of 5.88. Field sampling was performed for 24 months in order to quantify the density of edaphic arthropods. In the experimental plot (40 x 40 m), three horizons were sampled: L/F, H, and A (leaf litter fall, humus, and the first five cm of the mineral layer). A cylindrical corer with a diameter of 0.36 m was used as a sampling device. Five replicate samples were taken at each sampling.

A remarkably dense population of *Lithobius tricuspis*, comprising males, females and larvae, was recorded. Density fluctuations of this species, as well as horizon preferences, were analysed during the study. Mean density in the whole profile was 73.35 individuals/m^2 with a notable value of 39.17 individuals/m^2 in horizon H. Values of Usher index also indicated a preference for this horizon. In the whole of the soil profile, 36.84 % of the individuals were males]and females (adults and immature specimens) and 63.15 % corresponded to larvae (stadia L1, L2, L3 and L4). The sex ratio was 1.84. Finally, there was an attempt to interpret phenology of *L. tricuspis* through the correlation between mean density values and climatic parameters. Neither temperature, nor rainfall, nor water content had inluenced the monthly density distribution of adults. On the contrary, average monthly density in larvae, especially LIII and LIV, is positively correlated with the soil water content and negatively correlated with temperature.

INTRODUCTION

Lithobius tricuspis Meinert, 1872 is characterised by the enormous degree of variability in its morphological characters, including those used for identification, such as the 15 VaT spine, the accessory apical claws of the 15th legs, the number of prosternum teeth, and the number of spurs and shape of the claw of female gonopods (Eason 1965 1974; Serra 1980). Based on those characters, a large number of subspecies and varieties have been described, most of them being merely synonyms of the typical *L. tricuspis*, such as *L. tricuspis mononyx* Latzel, 1888, *L. tricuspis suevicus* Verhoeff, 1935, and *L. tricuspis multidens* Demange, 1958. Most specimens studied in the current work show the typical character states of the species, although some individuals present variations in the above character states. *Lithobius tricuspis* is the most abundant and common chilopod in the study area.

In this study, we present the temporal and spatial distribution of a population of *L. tricuspis* found in a Mediterranean forest soil. The large number of adult individuals and of each larval stage allowed us to determine the population composition throughout the sampling period. Results obtained have special interest considering that very few studies have been performed on the population biology of species belonging to the genus *Lithobius*.

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*Note that all Tables are presented at the end of the paper.

MATERIAL AND METHODS

Study site

The study site is located in the Parc Natural de Sant Llorenç del Munt i Serra de l'Obac, 35 km north-west of Barcelona. The study was performed in an experimental plot in a sclerophyllous forest at an altitude of 870 m, consisting mainly of *Quercus ilex* L., 1753 and *Pinus halepensis* Mill., 1768 trees, and *Arbutus unedo* L., 1753 was the most common bush species. The humus was of the leptomoder type, with a mean pH of 5.88 (measured in 1:2.5 water).

The climate of this region is typically Mediterranean. Figure 1 depicts the total rainfall and mean monthly temperatures recorded during the sampling period. These data were obtained from Terrassa's climatic station, located about 9 km SE from the study site. At the same time as samples were taken to obtain fauna, horizons H and A were sampled to estimate water content in the soil, which was measured as the percentage of weight loss in the sample after being heated to 60 °C for 24 hours.

Sampling procedures

Field sampling was performed over 24 consecutive months from June 1991 to May 1993. Three horizons, L/F, H, and A (leaf litter fall, humus, and the first five cm of the mineral soil respectively), were sampled in a 40 x 40 m experimental plot. A cylindrical corer 0.36 m in diameter (equivalent to 0.102 m^2) and 0.15 m in length was used as the

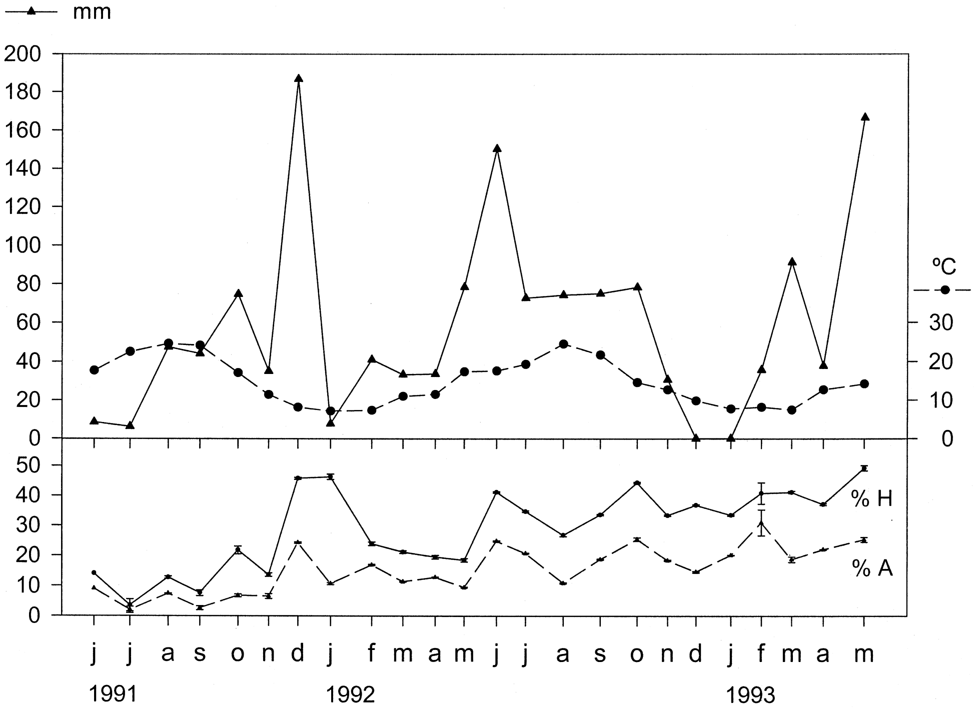

Fig. 1. Monthly rainfall (mm) and average temperatures (°C) recorded during the sampling period at the study site. Average monthly values (± standard error) of water content in horizon H (%H) and in horizon A (%A).

sampling device. Each monthly sample included five randomly placed samples. The three soil layers were successively extracted by hand from each sampling unit. The faunal components were obtained with Berlese-Tullgren extractors.

Identification of larval stages

Since larval development has not been studied in this species, the different stages were identified using the studies by Andersson (1978 1981) on morphology and taxonomy of

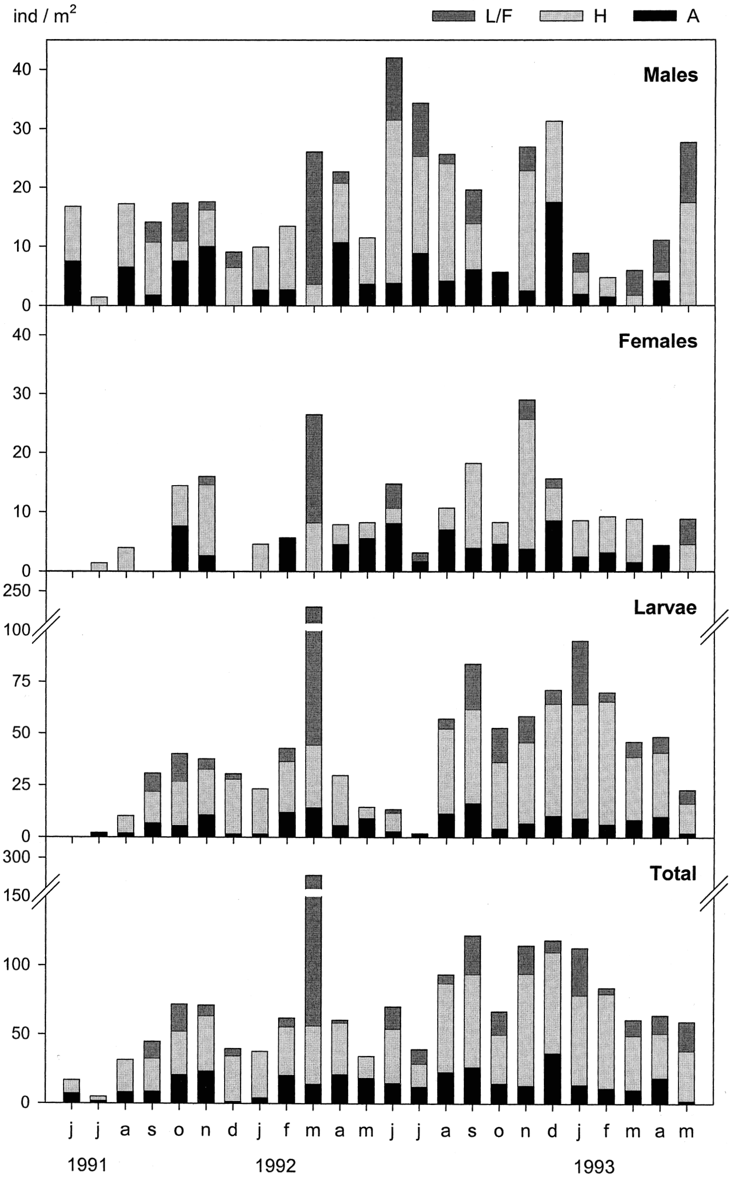

Fig. 2. Average monthly densities of males, females, larvae and total number of *Lithobius tricuspis* specimens captured in each level.

Lithobiomorpha species. Individuals were considered as larvae from stage L0 (7 pairs of legs) to stage LIV (12 pairs of legs). All the specimens presenting 15 pairs of legs were considered as adults and they were grouped according to sex. This adult category includes therefore the post-larval stadia PL1 to PL8 (juvenile + adult stadia).

Numerical methods

Data obtained over the 24 months of sampling were grouped in two periods, the first one (first year) corresponding to the first 12 months (June 1991 to May 1992) and the second one (second year) to the last 12 months (June 1992 to May 1993). Mean population density values were calculated as individuals/m^2, in each soil horizon, for each month (n=5), for each of the two years (n=12), and for the whole sampling period (n=24).

The Usher index was used to estimate the vertical distribution of the *L. tricuspis* population through the soil profile (Usher 1970). Depth values were designated for each horizon, being 3 for L/F, 2 for H, and 1 for A. For each monthly value of this index, a depth error was calculated. Morisita dispersion index (Morisita 1962, cited in Elliott 1977) was used to estimate the horizontal distribution of the population.

RESULTS

Density

Lithobius tricuspis was the most abundant centipede species in the sampled area. In total 903 specimens were captured, 561 of which were larvae and 342 were individuals with differentiated sexual structures.

Table 1 shows annual average density values (± standard error) for the first year, for the second year and for the whole of the study period. These densities were calculated for the total number of captured specimens, as well as for males, females and larvae separately and considering the different horizons in the soil profile. A value stands out (73.35 ± 11.13 individuals/m^2), which is a density value corresponding to the total number of specimens in the whole of the soil profile over the entire study period. This same table shows results (level of significance) the comparison between average monthly densities in the first and second year using the Mann-Whitney Rank Sum Test. Average male and female densities were not significantly different between the two years. Concerning larvae, average densities in horizon H and in the whole of the soil profile were significantly higher during the second year. Considering all specimens, A was the only horizon where there were not significant differences between density values in the first and second years.

Table 2 shows annual average density values (± standard error) of different larval stages in the first year, in the second year and over the whole of the study period. There were only statistically significant differences between LIV density values in the first and second years in horizon H and in the whole of the soil profile.

Figure 2 shows average monthly densities of males, females, larvae and total number of *L. tricuspis* specimens captured in each level. In order to check whether differences between average density values were statistically significant, an analysis of variance using the Kruskal-Wallis (KW) test and a multiple comparison with the Student-Newman-Keuls (SNK) method were performed for each one of the specimen groups considered, and for each horizon in the soil profile. Concerning males and females, either the KW test does not detect differences or, when it does, the SNK ($p<0.05$) test cannot differentiate between

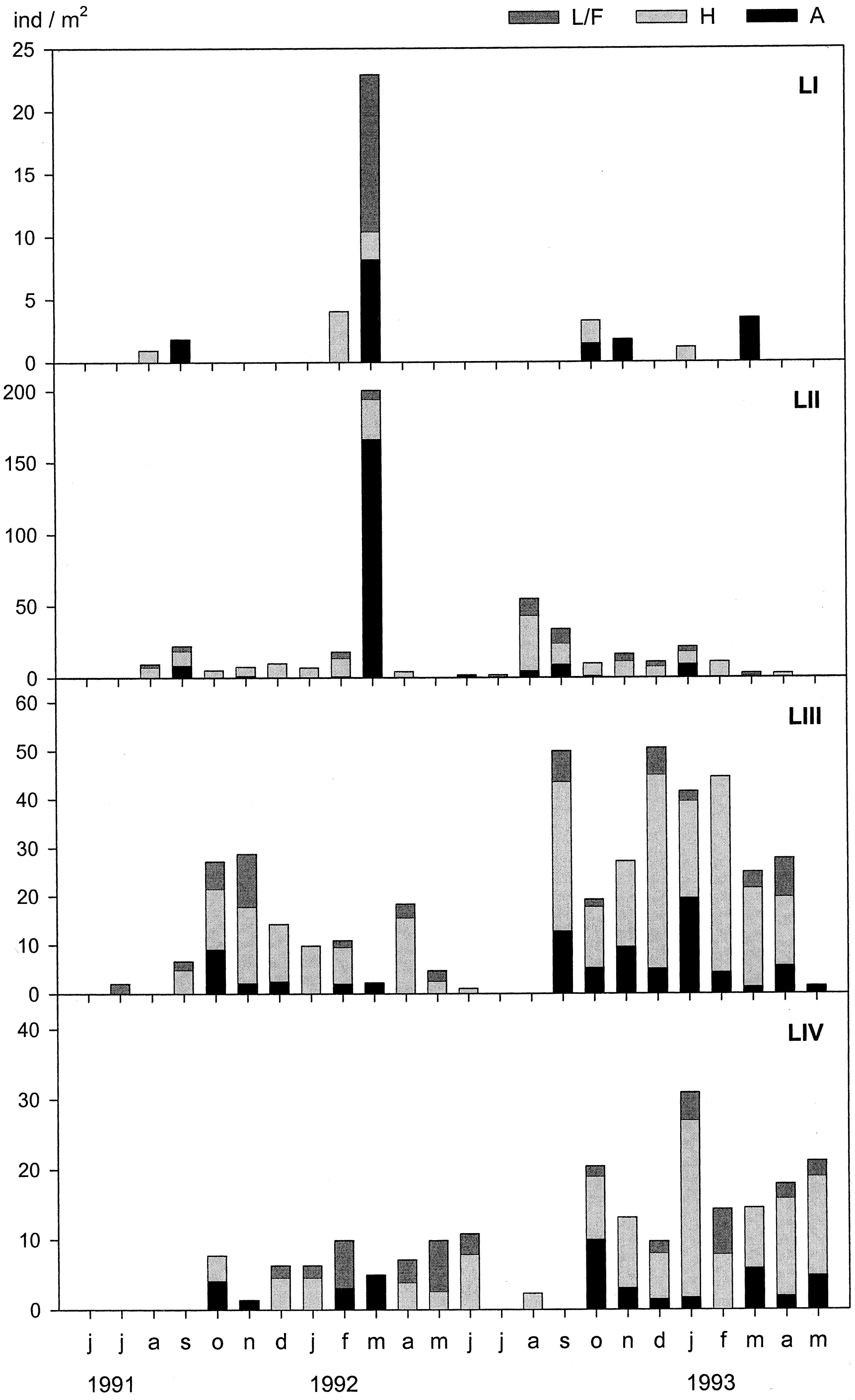

Fig. 3. Average monthly densities of LI, LII, LIII and LIV larval stages of *Lithobius tricuspis* captured in each edaphic horizon.

which months these differences appear. When considering the total number of individuals, and except for horizon A, these tests detect some differences between average monthly densities. These differences were mainly due to the effect produced by larvae densities. Variance analysis shows that, excepting horizon A, in horizons L/F and H as well as in the whole of the soil profile, ($p<0.001$) average densities of the larvae presented statistically significant differences during the months of the study. Figure 3 shows average monthly densities for each larval stage. Density values for LII in the most superficial horizon were exceptionally high in March (first year).

Spearman's rank correlation analyses between monthly population density values of males and females in different horizons and abiotic parameters (average monthly air temperature, accumulated rainfall and soil water content in horizons H and A), showed that, in most cases, they were not significantly correlated ($p<0.05$). It is remarkable that correlation slopes (positive or negative) are very variable for any of the parameters considered. Regarding density of larvae (mainly stages LIII and LIV), there are statistically significant correlations, which are negative against temperature and positive against accumulated rainfall and soil water content.

Vertical and horizontal distributions

Concerning the vertical distribution along the soil profile, figure 4 shows the Usher index values, which provide an estimate of the mean depth at which each stadium occurred during the sampling period. Table 3 shows average values of the Usher index in the first and second years, and for the whole of the study period. Comparative analyses of these values for the 24 months shows that males and larvae tended to be placed in horizon H, while females were spread between horizons H and A (KW $p<0.05$, Dunn $p<0.05$). Regarding different larval stages, although LI were positioned in the deepest horizon, Usher index values are not significantly different (KW n.s.).

On the other hand, significant differences between monthly densities in the different horizons were found. Table 4 shows the results of density comparisons made between different levels. Males and larvae showed density values significantly higher in horizon H, while females had similar densities in horizons H and A, and significantly lower in horizon L/F. Individuals in stages LII and LIII also showed higher densities in horizon H.

Concerning horizontal distribution, Table 5 shows average monthly values of Morisita index for each of the horizons and for each of the larval and adult stages. Considering that a random distribution has a value of one, and that the distribution of maximum contagion corresponds to five, males and females were randomly distributed (1.26 and 1.05 respectively when taking into account all the horizons). Regarding larvae, index values were slightly higher, particularly in LI and LII. This indicates that individuals in these larval stages tended to be distributed in patches.

Population composition

Considering all the specimens captured in the whole of the soil profile over the entire study period, 36.85 % were adult specimens and 63.15 % were larvae (note the classification criteria of different stages commented on in the density paragraph). From the total adult individuals, 64.80 % were males and 35.20 % were females. This means that the ratio between males and females was 1.84 in the whole of the soil profile, 2.70 in horizon L/F, 1.86 in horizon H and 1.44 in horizon A. Sex ratios were 1.99 and 1.74

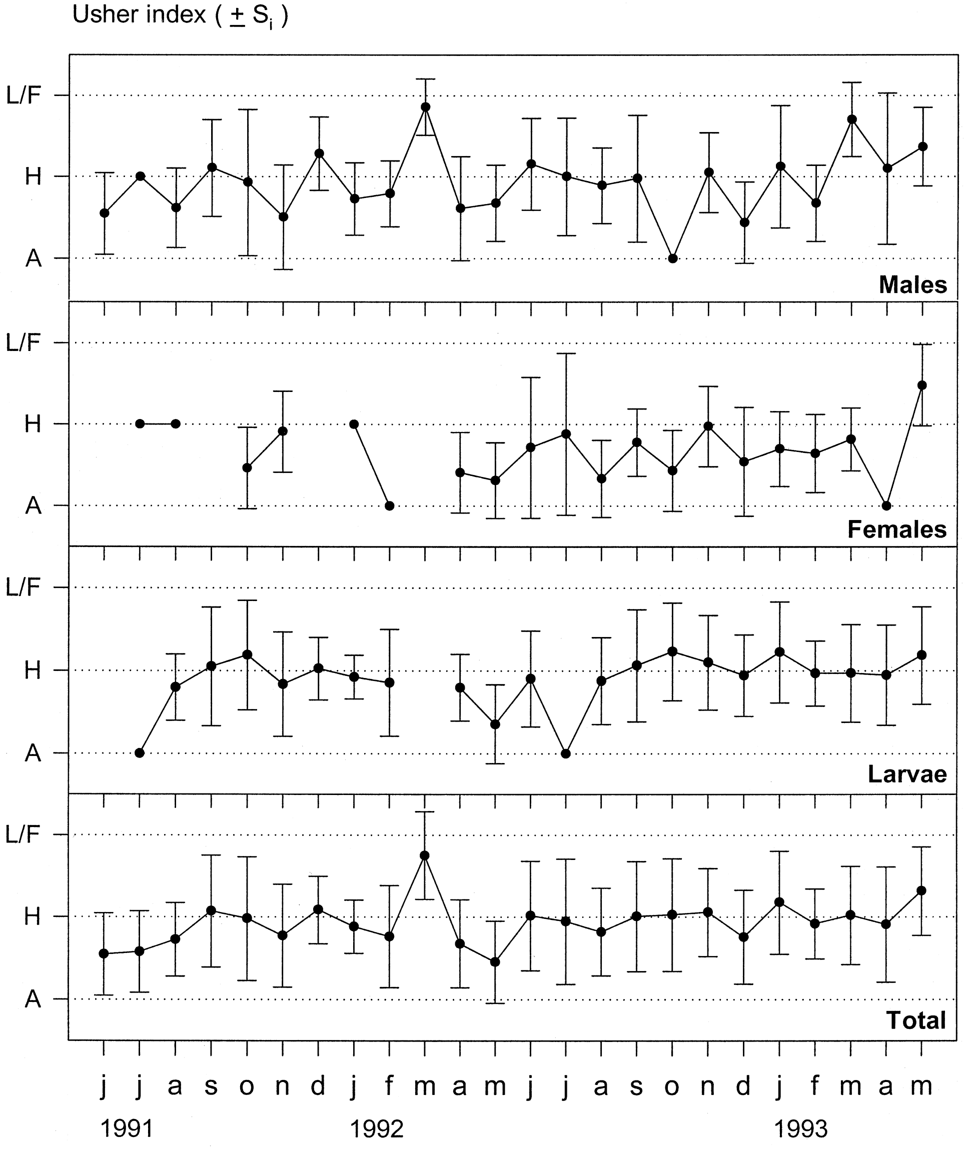

Fig. 4. Monthly Usher index values (± depth error) of males, females, larvae and total specimens of *Lithobius tricuspis*.

for the first and second years respectively. The proportion of larvae for the entire soil profile were LI 3.54 %, LII 40.60 %, LIII 37.12 % and LIV 18.74 %.

DISCUSSION

Comparison and interpretation of data in the current study are difficult because of the lack of information on composition, density and distribution in space and time for populations of Lithobiomorpha species. Most published works give punctual density data at a general Chilopoda level, or, at the most, at an order level. The average density of *L. tricuspis* (73.35 individuals/m^2) is surprisingly high when compared to the average density of *Glomeris marginata* (40.34 individuals/m^2, Miquel 2000) or really low when compared to that of *Polyxenus lagurus* (376.2 individuals/m^2, Miquel *et al.* 2000), the two species that were studied in the same area during the same time period. This average density is also high when compared to values obtained by Albert (1979) on populations of two *Lithobius* species from a beechwood forest near Göttingen (Germany), who found average densities of 41 individuals/m^2 in *Lithobius mutabilis* and 32 individuals/m^2 in *Lithobius curtipes*. Differences in the type of forest and climatology might explain the difference between these densities and the one obtained in the current work.

Analysis of the temporal distribution of the *L. tricuspis* population shows that male and female densities were not significantly different between different months. Also, comparison between first and second year distributions shows that populations of adult individuals were not different between the two years. Regarding larvae, analysis of the temporal distribution shows that there were differences between monthly densities and between the first and second years. Monthly differences were mainly due to the exceptionally high density of LII in March of the first year, while annual densities indicate that LIV had a higher density during the second year. These results agree with those obtained by Albert (1979), who found different abundance of *L. mutabilis* and *L. curtipes* larvae between different years, while adult populations remained constant.

Lithobius tricuspis occurred in all of the sampled horizons. The average density values recorded in each edaphic horizon, as well as the Usher index values, clearly indicate that males and most larvae preferred organic horizon H. Females and LI tended to be placed at a deeper level, spreading across horizons H and A. This female preference for deeper soil horizons could be related to egg layout. Abundance of mineral components in horizon A would provide females with the necessary particles to make egg covers (Demange 1956; Albert 1983; Serra & Miquel 1996). The production of eggs here could also explain the higher density of larvae at early developmental stages in horizon A. On the other hand, relatively high values of the Morisita index suggest that larvae at early developmental stages tended to be distributed in patches. If recruitment occurred in horizon A, larvae L0, LI and LII would mainly remain in this level, and they would not disperse and migrate to higher horizons until they reached further developmental stages.

From correlation analyses between average monthly density values in different horizons and the abiotic parameters, it becomes clear that neither temperature, nor rainfall, nor water content had an influence on the monthly density distribution of adult individuals. On the contrary, average monthly density in larvae, especially LIII and LIV, was positively correlated with the soil water content and negatively correlated with temperature. These results partly agree with those published by Albert (1983), who found that in temperature preference tests, specimens of *L. mutabilis* and *L. crassipes* occur at a wide range of temperatures, and in humidity preference tests with sieved litter they only occurred in litter with more than 50 % water content. It must be kept in mind, though, that those species come from a beechwood forest with climatological features that are very different from those of the mediterranean sclerophyllous forest studied in this paper.

Population composition analyses show that larvae were more abundant than adult individuals. L0 specimens were not found in any of the samplings, which could be explained by a short life of the individual as L0, as happens in other species such as

Lithobius pilicornis (Serra & Miquel 1996) where L0 takes two or three days before it moults into LI, and LI takes between four and eight days to moult into LII. Based on this hypothesis, the presence of LI and LII specimens would indicate the months when recruitment occurs, which would be practically any month of the year in the case of *L. tricuspis*. There was a remarkable peak of LI density between the end of winter and the beginning of spring of the first sampling period. On the other hand, during this same time of the year in the second sampling period, the density values of LI were considerably lower. These results differ from those recorded by Albert (1979 1982 1983), who suggested that recruitment of *L. mutabilis* and *L. crassipes* occurs in the spring and at the beginning of summer, and that these species lay eggs throughout the year with a peak in the spring. This behaviour also occurs in a *Lithobius forficatus* population from a mixed deciduous woodland at Yorkshire (U.K), while another population of *Lithobius variegatus* from the same forest does not show any increment of egg layout in the spring (Lewis 1965). Unfortunately, we do not have any information on the egg laying periods for *L. tricuspis* to allow the comparison with these trends.

Concerning sex ratio, the number of males was considerably larger than the number of females, and there were not remarkable differences between the two study years. The lack of data on the biology and life cycle of *L. tricuspis*, such as longevity or cannibalism, makes it difficult to explain why the number of males was almost twice the number of females.

ACKNOWLEDGEMENTS

This work was supported by a grant from the Spanish Ministry of Education and Science (PB92-0857).

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TABLE 1.

Annual average densities ± standard error (individuals/m^2) in the first and second year and during the whole of the study period recorded in each horizon, and in the whole of the soil profile. Level of significance in the comparison of monthly average densities between first and second year is indicated by using the Mann-Whitney Rank Sum Test (M-W n.s.= not significant; *= p<0.05).

	Level	**Total**	**1st year**	**2nd year**	**M-W**
FEMALES	L/F	3.83 ± 1.06	3.18 ± 1.84	4.48 ± 1.11	n.s.
	H	9.10 ± 1.44	7.11 ± 0.88	11.09 ± 2.67	n.s.
	A	4.58 ± 0.87	4.45 ± 1.13	4.72 ± 1.38	n.s.
	Total	17.51 ± 2.10	14.74 ± 1.87	20.29 ± 3.69	n.s.
MALES	L/F	1.42 ± 0.78	1.64 ± 1.52	1.21 ± 0.49	n.s.
	H	4.90 ± 1.06	3.55 ± 1.09	6.24 ± 1.78	n.s.
	A	3.19 ± 0.60	2.20 ± 0.85	4.18 ± 0.77	n.s.
	Total	9.51 ± 1.57	7.39 ± 2.32	11.63 ± 2.02	n.s.
LARVAE	L/F	14.30 ± 7.64	18.49 ± 15.3	10.10 ± 2.60	n.s.
	H	25.17 ± 3.54	16.39 ± 3.02	33.95 ± 5.41	*
	A	6.85 ± 0.93	6.11 ± 1.38	7.60 ± 1.27	n.s.
	Total	46.32 ± 9.58	40.99 ± 17.7	51.66 ± 8.03	*
TOTAL	L/F	19.55 ± 9.21	23.31 ± 18.6	15.79 ± 2.54	*
	H	39.17 ± 4.22	27.05 ± 3.58	51.29 ± 5.91	*
	A	14.63 ± 1.75	12.76 ± 2.35	16.50 ± 2.57	n.s
	Total	73.35 ± 11.13	63.12 ± 20.9	83.58 ± 8.00	*

TABLE 2.

Annual average densities ± standard error (individuals/m^2) of different larval stages in the first and second year, and during the whole of the study period, registered in each horizon and in the whole of the soil profile. Level of significance in the comparison between monthly average densities between first and second year using the Mann-Whitney Rank Sum Test (M-W, n.s.= not significant; *,=p<0.05; **= p<0.005).

	Level	**Total**	**1st year**	**2nd year**	**M-W**
LI	L/F	0.52 ± 0.52	1.04 ± 1.04	0.00	n.s.
	H	0.42 ± 0.20	0.60 ± 0.37	0.24 ± 0.17	n.s.
	A	0.69 ± 0.37	0.83 ± 0.68	0.56 ± 0.32	n.s.
	Total	1.64 ± 0.96	2.47 ± 1.89	0.80 ± 0.38	n.s.
LII	L/F	8,50 ± 6.90	14.80 ± 13.8	2.21 ± 1.04	n.s.
	H	8.10 ± 1.85	7.54 ± 2.19	8.65 ± 3.07	n.s.
	A	2.21 ± 0.67	1.33 ± 0.62	3.08 ± 1.16	n.s.
	Total	18.81 ± 8.30	23.67 ± 16.2	13.94 ± 4.69	n.s.
LIII	L/F	3.49 ± 1.01	1.52 ± 0.76	5.46 ± 1.72	n.s.
	H	11.48 ± 2.48	6.66 ± 1.79	16.31 ± 4.27	n.s.
	A	2.23 ± 0.61	2.22 ± 0.93	2.23 ± 0.84	n.s.
	Total	17.20 ± 3.44	10.40 ± 2.88	24.01 ± 5.73	n.s.
LIV	L/F	1.78 ± 0.53	1.13 ± 0.54	2.43 ± 0.90	n.s.
	H	5.17 ± 1.26	1.59 ± 0.59	8.74 ± 2.00	**
	A	1.73 ± 0.47	1.72 ± 0.77	1.73 ± 0.58	n.s.
	Total	8.68 ± 1.67	4.45 ± 1.14	12.91 ± 2.66	*

TABLE 3.

Average values of the Usher index (± depth error) in the first and second years and for the whole of the study period.

Total	**Males**	**Females**	**Larvae**	
1st year	1.86 ± 0.53	1.89 ± 0.49	1.64 ± 0.52	1.79 ± 0.67
2nd year	2.00 ± 0.61	1.96 ± 0.55	1.69 ± 0.52	1.95 ± 0.52
Total	1.93 ± 0.57	1.92 ± 0.52	1.67 ± 0.52	1.88 ± 0.59
	LI	**LII**	**LIII**	**LIV**
1st year	1.80 ± 0.23	1.92 ± 0.09	1.92 ± 0.08	2.05 ± 0.11
2nd year	1.39 ± 0.12	2.09 ± 0.09	2.20 ± 0.08	2.04 ± 0.05
Total	1.59 ± 0.18	1.99 ± 0.31	2.06 ± 0.38	2.05 ± 0.43

TABLE 4.

Results of density comparisons between different horizons. Level of significance of Kruskal-Wallis test (K-W) and a multiple comparison with the Student-Newman-Keuls method (SNK) (n.s.= not significant; *= p<0.05; **= p<0.005; ***= p<0.001; H, L/F, A indicate annual average densities in each one of the horizons).

	Total	**Males**	**Females**	**Larvae**
K-W	***	**	**	***
SNK	H>L/F=A	H>L/F=A	H=A>L/F	H>L/F=A
	LI	**LII**	**LIII**	**LIV**
K-W	n.s.	**	*	n.s.
SNK	—	H>L/F=A	H>A=L/F	—

TABLE 5.

Average monthly values of Morisita index (± standard error) for each of the horizons and for each of the adult and larval stages.

Level	Total	Males	Females	Larvae
L/F	1.75 ± 0.33	1.00 ± 0.46	1.79 ± 1.18	1.37 ± 0.36
H	1.69 ± 0.22	1.40 ± 0.33	1.69 ± 0.48	1.68 ± 0.20
A	1.48 ± 0.18	1.38 ± 0.48	1.44 ± 0.60	1.95 ± 0.36
Total	1.34 ± 0.06	1.26 ± 0.15	1.05 ± 0.26	1.52 ± 0.11
Level	**LI**	**LII**	**LIII**	**LIV**
L/F	---	1.75 ± 0.86	2.13 ± 0.54	1.64 ± 0.89
H	---	2.41 ± 0.38	1.30 ± 0.12	1.86 ± 0.52
A	2.50 ± 2.50	2.23 ± 0.84	1.67 ± 0.71	2.50 ± 1.12
Total	2.08 ± 1.50	2.40 ± 0.38	1.27 ± 0.14	1.36 ± 0.21